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Evaluation of the Pollution Levels of Landfill Sites – The Landfill Pollution Index (LPI)

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ABSTRACT

Most of the solid waste disposal sites in Malaysia are either open dumps or controlled tipping. The pollution levels from these sites are expected to be high especially the contamination of soil, air, surface and underground water. All these pollutions have direct and indirect links to human being. The risks associated with solid waste disposal sites involved three compartments or media, i.e. the atmosphere, water and soil. This 'Cross media' or 'Multimedia' impacts phenomenon has been recognized in various countries as being of potential importance and complicated. This study discusses the development of a new and simple evaluation system to assess the pollution levels of landfill sites. The Landfill Pollution Index (LPI) was introduced, which incorporated with 4 other sub-indices, i.e. the Environmental Degradation Index (EDI) for water quality, gas emission, chemicals in surface water and chemicals in groundwater. Active and closed landfill sites in Kuala Lumpur were assessed by using the LPI approach. The results show that Taman Beringin was the most polluted landfill with the LPI of 719.56, followed by Jinjang Utara (383.51), Paka 1 (197.66), Brickfields (128.90), Paka 2 (113.72), Sri Petaling (30.81) and Sungei Besi (17.87). For detailed evaluation, the LPI calculated and was further elaborated by using the sub-indices, i.e. the EDI. The results provide information on the extent of pollution at each particular landfill site in terms of different components such as water quality, gas emission, soil and groundwater. This helps the landfill operators as well as decision makers in giving priority to remedial or rehabilitate the environmental conditions of the landfill sites. In summary, a new evaluation system had been introduced in this study in order to produce simple and reliable tool to evaluate or assess the pollution levels for municipal waste landfill sites. Based on the assessment of Kuala Lumpur landfill sites, it can be concluded that the risk and pollution levels of landfill sites in Kuala Lumpur area are relatively high, but it is site-specific and varies from one landfill site to another.

ABSTRAK

Kebanyakan tapak pelupusan sisa pepejal di Malaysia dikendalikan sama ada secara terbuka ataupun secara kawalan. Kadar pencemaran daripada tapak *pelupusan ini dijangka lebih tinggi terutamanya pencemaran tanih, udara, air permukaan dan bawah tanah. Kesemua pencemaran ini secara langsung dan tidak langsung berkait dengan manusia. Risiko yang dikaitkan dengan tapak pelupusan sisa pepejal melibatkan tiga bahagian atau media iaitu atmosfera, air dan tanih. Kesan fenomena 'media rentas' atau multimedia dikenalpasti di kebanyakan negara sebagai potensi penting dan rencam. Kajian ini membincangkan pembangunan sistem penilaian baru dan mudah untuk menilai tahap pencemaran tapak pelupusan sampah. Indeks Pencemaran Tapak Pelupusan (LPI) diperkenalkan yang menggabungkan dengan sub-indeks iaitu Indeks Degradasi Alam Sekitar (EDI) untuk kualiti air, pelupusan gas, kimia dan air permukaan dan bawah tanah. Tapak pelupusan tertutup dan aktif di Kuala Lumpur dinilai menggunakan pendekatan LPI. Keputusan menunjukkan bahawa Taman Beringin adalah tapak pelupusan yang paling tercemar dengan LPI 719.56 diikuti oleh Jinjang Utara (383.51), Paka 1 (197.66), Brickfield (128.90), Paka 2 (113.72), Sri Petaling (30.81) dan Sungei Besi (17.87). Penilaian yang mendalam dengan menggunakan sub-indeks (EDI) turut dijalankan. Keputusannya menyediakan maklumat pencemaran pada setiap tapak pelupusan dan komponen yang berbeza seperti kualiti air, pelepasan gas, tanih dan air bawah tanah. Ini membantu operator tapak pelupusan tanah dan pembuat keputusan dalam memberikan perhatian untuk memperbaiki keadaan persekitaran tapak pelupusan. Ringkasnya, sistem penilaian baru diperkenalkan dalam kajian ini untuk menghasilkan 'alat' yang mudah dan sah untuk menilai tahap pencemaran tapak pelupusan perbandaran. Berdasarkan tapak pelupusan Kuala Lumpur, disimpulkan bahawa risiko dan aras pencemaran tapak pelupusan sampah di Kuala Lumpur secara relatifnya tinggi, tetapi inimerupakan tapak-khusus dan berbeza daripada tapak pelupusan yang lain.*

INTRODUCTION

Landfilling is the most widely used method of solid waste disposal in the world. It has the longest history, the widest range of capabilities and in most instances, is the least expensive waste disposal method (Weiss 1974). Most of the existing solid waste disposal sites in developing countries are practising either open dumping or controlled tipping because the technology of proper sanitary landfill practice is not totally implemented (Lee & Sivapalasundram 1979; Lee & Krieger 1986; Matsufuji & Sinha 1990). The environmental conditions from these sites are thus expected to be bad especially in terms of the contamination of soil, air, surface and underground water.

The assessment of the pollution levels from the landfill sites requires a comprehensive study that takes into account related parameters, which provide the overall perspectives of the pollution of the landfill sites. In this study, a new approach of assessing the pollution levels of landfill sites was developed, which focuses on 4 major components, i.e. water quality, gas emission, chemicals in soil and chemicals in groundwater.

Information and knowledge on the pollution levels are very important to decision makers as to the consequences of any possible actions to be taken such as selecting waste treatment or disposal options, remediating contaminated sites and siting new facilities (Tchobanoglous & O'Leary 1994). However, it should be emphasised that knowing the pollution levels is only one of many information used, and the final decisions are usually driven by political, social and economic factors.

STUDY AREA AND METHODOLOGY

Study Area

The study area is the Federal Territory of Kuala Lumpur. Kuala Lumpur has a total area of 234 km^2 and it is characterised by highly populated, urbanised, and the most industrialised area in the country. As the centre of administration, industrialisation, commerce, finance and culture, Kuala Lumpur is experiencing rapid population growth. By assuming the population average growth rate of 2.5 percent, the area is expected to have about 3 million people by the year 2020 and the waste generated is expected to increase to about 5,000 tonnes per year (Nasir et al. 1995; Nasir et al. 1996).

There are ten (10) dumping sites used to receive solid wastes in the study area and out of these, seven (7) were selected for the study, i.e. Sri Petaling, Brickfields, Taman Beringin, Jinjang Utara, Sungei Besi, Paka 1 and Paka 2. Taman Beringin is the only site that is still receiving wastes or still in operation during the study period, while the rest of the sites have been closed.

Calculation of Environmental Degradation Index (EDI) and Landfill Pollution Index (LPI)

The method developed by Battelle Columbus Laboratories was modified in this study to translate the pollution levels of landfill sites into Environmental Degradation Index (EDI) and Landfill Pollution Index (LPI), which emphasise on the development of weightage for different parameters used in the evaluation. The methods of developing the weightage for parameters, Landfill Pollution Index (LPI) and Environmental Degradation Index (EDI) are discussed below.

Weighting or Ranking of Parameters - Delphi Approach

The development of a representative weightage for each parameter was based on the Delphi Method. The procedure involved a selection of a group of experts and each of these individuals was asked to rank the parameters according to their importance from a fixed number of weighting units, and then through second round of feedback asking them to revise their response toward a group mean (Lowe & Lewis 1980; Turner & O'Riordan 1982; Richey et al. 1985).

Based on the scores given by each expert, a representative weightage for each selected physical parameter can be obtained. In the survey, the experts were asked to rate the importance of each physical parameter ranging from the scale of '1' if that parameter is the most significant to the scale of '10' if the parameter is the least important. The raw data given by the experts were evaluated as follows (Low 1995; Lai 1997):

The average score for each parameter:

$$V_x = \left(\sum_{i=1}^{e} S_{xi} \right) / e$$

where: V_x = Mean of each parameter from X = 1 for the 1st parameter to X = n for the nth parameter

S_{xi} = Score that an expert i (i = 1 to e) put on the importance of parameter X from X_1 = 1st parameter to X_n = nth parameter

e = Total number of experts

This process is done for all the parameters. In general, we could expect that a parameter with the least score is the most critical or important. In other words, the lower is the average score, the more critical is the parameter. The average score for each parameter was then used to evaluate the 'temporary weights' which were evaluated using the following formula:

Temporary Weight for parameter X (TW_x) = V_m / V_x

where: V_m = The lowest mean value among the parameters or the base data in which other parameters are to be compared with.

V_x = Mean of each parameter where X = 1 for the 1st parameter and X = n for the nth parameter.

The evaluation of the final weightage is as follows:

Final Weightage for parameter X (FW_x) = TW_x / Q - for 0 to 1 basis

Final Weightage for parameter X (FW_x) = (TW_x / Q) x 100 - for 0 to 100 basis

where: nQ = Σ (TW_x)

$x = 1$

Q = Total of all temporary weightage.

TW_x = Temporary weightage of each parameter from $X = 1$ for the 1^{st} parameter to $X = n$ for the n^{th} parameter.

The main application of the 'Temporary Weights' is to seek a set of weights for all the parameters which would add up to 1 or 100.

Environmental Degradation Index (EDI)

The calculation of the environmental degradation index (EDI) relied on the damage function or dose response curves for each particular pollutant. The general formula for the calculation is as follows:

$$EDI = \sum_{x=1}^{n} (D_x \ x \ FW_x)$$

where: X = 1 ..... n and represents the parameters relevant to the study

D_x = the damage from each parameter resulted from the dose-response relationship

FW_x = the subjective final weightage of each parameter

The dose-response relationships were determined for all the parameters based upon the results of Delphi surveys on experts and also checklists on the conditions of all landfill sites. Dose-response graphs were plotted and the equations were derived based on the USEPA recommendation. The dose-response assessment was a linear model where the responses at high level doses are extrapolated to low doses by a straight line to the origin (0).

Table 1 shows an example of the calculation of EDI for different pollutants which exceed the tolerable or threshold levels. Column 1 shows the quantities or concentration of emissions of each parameter detected given in lb/hr. The damage index (D) shown in column 2 is calculated by interpolating from damage functions or dose response curves estimated for that particular pollutant.

In column 3, the weightage for the pollutants is taken directly from the data derived from the Delphi experiment and the damage potential of the pollutant is computed in column 4, which was done by multiplying column 2 and 3. The EDI is arrived at by adding the damage potentials of the pollutants, and the total scores are divided by 100 for ease of comparison.

Table 1. Example of EDI calculation

Pollutant	Quantity (lb/hr)	Damage Index (D)	Final Weight (FW)	D x FW
NO_x	6,900	690	48	33,120
SO_2	43,700	1,823	58	105,734
Particulates	88,320	1,853	45	83,385
Total organics	120	1.2	45	54
Suspended solids	-	-	-	
Heat	4,600	46	8	368
Ash	22,080	221	4	884
TOTAL				223,545
	EDI			2,235

Source: Lowe and Lewis 1980

Landfill Pollution Index (LPI)

The Landfill Pollution Index (LPI) was defined as:

$$LPI = EDI_u - EDI_i$$

Where: EDI_u = Environmental Degradation Index for parameters exceeded the tolerable levels (uncontrolled cases).

EDI_i = Environmental Degradation Index for parameters at tolerable levels (controlled cases).

In this study, EDI_u is assumed to represent the current actual condition of landfill site, while EDI_i represents the lowest limit or the tolerable point. Thus, the LPI obtained in the study is actually a value showing how much the pollution levels exceeding the tolerable limit of landfill sites.

According to Hansson (1997), the toxicological database is insufficient for most substances, and the scientific interpretation of toxicological data is complex and controversial. All dose-response relationships used in the study were based on the common assumption, i.e. "linear extrapolation to zero" method for establishing exposure guidance values (Wilson 1997). For cases where the damage functions or dose-response curves are not available for certain parameters, decisions can be made to exclude the parameters from the evaluation or to estimate the curves from that of similar compounds (Asante-Duah 1993).

RESULTS AND DISCUSSION

Development of Weightage Dose-Response Relationships

The weightage and dose response equations obtained by using the Delphi Method were summarised in Table 2.

Table 2. Summary of the dose response equations

No.	Parameters	Weightage	Dose Response Equations
Water Quality Parameters			
1	BOD	3.2934	y = 1.1928x
2	COD	0.4117	y = 0.0742x
3	Chromium (Cr)	0.6467	y = 2109.6x
4	Lead (Pb)	0.6467	y = 0.998x
5	Mercury (Hg)	0.6467	y = 150.4x
6	Suspended Solids (SS)	0.5489	y = 0.1914x
7	Manganese (Mn)	0.6467	y = 35.917x
Gas Emission Parameters			
8	Carbon Dioxide (CO_2)	1.6467	y = 0.00008x
9	Sulphur Dioxide (SO_2)	1.0978	y = 0.002x
10	Hydrogen Sulphide (HS)	0.8234	y = 0.0002x
11	Vinyl Chloride (VC)	0.6587	y = 3.4349x
12	Styrene	0.5489	y = 3.1531 x
13	Benzene	0.4705	y = 723.4x
14	Ammonia	0.3659	y = 1.3249x
15	Carbon Monoxide (CO_2)	0.3293	y = 1.2385x
Chemical Parameters in Soil			
16	Benzene	3.2934	y = 642.34x
17	Vinyl Chloride	1.0978	y = 533.44x
18	Ethylbenzene	0.6587	y = 250.11x
19	Lead	1.0978	y = 0.1688x
20	Chromium	0.6587	y = 0.1129x
Chemical Parameters in Groundwater			
21	Benzene	3.2934	y = 4000x
22	Vinyl Chloride	1.0978	y = 3888.9x
23	Ethylbenzene	0.6587	y = 2985.1x
24	Lead	1.0978	y = 69.778x
25	Chromium	0.6587	y = 422.09x
26	Arsenic	1.6467	y = 289.44x

The damage functions or dose-response relationships were determined for all the parameters of three criteria in indicating the pollution levels of landfill sites. The development of the dose-response curves for all relevant parameters were carried out based upon the results of checklists on the conditions of all landfill sites. Based on the method recommended by USEPA, the model used for the dose-response assessment was a linear model where the responses at high level doses are extrapolated to low doses by a straight line to the origin (0) except for some “special” parameters such as pH and dissolved oxygen (DO) which give different styles of responses against the doses. The dose-response relationships for some parameters are excluded in the study because these chemicals were not detected in the samples in the study area.

Threshold limits for parameters

Threshold Limit Values (TLVs) or maximum exposure level of the parameters were gathered from various sources such as the American Council of Government Industrial Hygienists (ACGIH), Environmental Protection Agency (EPA), National Institute of Occupational Safety and Health (NIOSH), US Occupational Health and Safety Administration (OSHA), the World Health Organization (WHO) and the Air Quality Guidelines for Europe.

It is difficult to have the threshold limit values for all parameters in different media of pollution such as groundwater, soil and surface water from a single source. In this study, threshold limit values from various sources were used. The threshold limit values used in this study are summarised in Table 3.

The threshold limit values for chemicals in soil and groundwater were referred to the Malaysian Environmental Impact Assessment Guidelines for Groundwater and/or Surface Water Supply Projects developed by Department of Environment Malaysia were used. As for water quality parameters, Standards B of the Environmental Quality Act (EQA) Regulations, 1974 were used as the threshold limit values.

For gas emissions, the threshold limit values developed by the American Council of Governmental Industrial Hygienists (ACGIH) were used. The values used for comparison of gas emission parameters were the Time-Weighted Average (TLV-TWA) values, i.e. the average concentration for a normal 8-hours workday and a 40-days workweek, to nearly all workers that may be repeatedly exposed.

According to the method recommended by Asante-Duah (1993), if toxicity data such as the threshold values is not available for a particular parameter, decision can be made to exclude the parameter from the evaluation procedure. In this study, there were 9 parameters which were decided to be excluded from the EDI evaluation procedure because no toxicity data was available or exist for these parameters, namely methane and freon-11 gases, 1,4-dichlorobenzene and selenium in both soil and groundwater. For water quality parameters, DO and ammonia nitrogen were excluded because no specific threshold limits were found in Malaysia. pH value was also excluded from the evaluation because the standards provides a range of pH values and no specific pH value could be used as the limit.

Table 3. Data used as threshold limit values in the study

Parameters	Threshold Limit Values	Intervention Values	Unit	Sources
BOD (w)	20	50	mg/L	A
COD (w)	50	100	mg/L	A
Chromium (w)	0.05	0.05	mg/L	A
Lead (w)	0.1	0.5	mg/L	A
Mercury (w)	0.005	0.05	mg/L	A
Manganese (w)	0.2	1.0	mg/L	A
Suspended Solids (w)	50	100	mg/L	A
Carbon Dioxide (g)	5,000	5,000	ppm	B
Sulphur Dioxide (g)	2.0	2.0	ppm	B
Hydrogen Sulphide (g)	10.0	10.0	ppm	B
Vinyl Chloride (g)	5.0	5.0	ppm	B
Styrene (g)	50.0	50.0	ppm	B
Benzene (g)	10.0	10.0	ppm	B
Ammonia (g)	25.0	25.0	ppm	B
Carbon Monoxide (g)	25.0	25.0	ppm	B
Benzene (s)	0.05	1.00	mg/kg	C
Vinyl Chloride (s)	0.001	0.10	mg/kg	C
Ethylbenzene (s)	0.05	50.0	mg/kg	C
Mercury (s)	0.3	10.0	mg/kg	C
Cyanide (s)	1.0	-	mg/kg	C
Arsenic (s)	29	55	mg/kg	C
Lead (s)	85	530	mg/kg	C
Chromium (s)	100	380	mg/kg	C
Benzene (gw)	0.0002	0.03	mg/L	C
Tetrachloromethane (gw)	0.00001	-	mg/L	C
Vinyl Chloride (gw)	0.00001	0.0007	mg/L	C
Ethylbenzene (gw)	0.0002	0.15	mg/L	C
Mercury (gw)	0.00005	0.00003	mg/L	C
Cyanide (gw)	0.005	-	mg/L	C
Arsenic (gw)	0.01	0.06	mg/L	C
Lead (gw)	0.015	0.075	mg/L	C
Chromium (gw)	0.001	0.03	mg/L	C

Notes: *Source A* =(Environmental Quality Act and Regulations. 1996)
Source B = (ACGIH. 1995)
Source C = (DOE. 1997)

Calculation of the Environmental Degradation Index (EDI)

An example of the EDI calculation for parameters exceeding the threshold limits for Taman Beringin Landfill is shown in Table 4. For

EDI_i calculation or the control cases, which has taken into account all the threshold limits and target values, the results are tabulated in Table 5. It is important to emphasise that the EDI_i for each different landfill will have different values based on the total number of parameters exceeded the threshold or limit values. For Taman Beringin case, there were 16 parameters exceeded the thresholds and the total EDI_i evaluated was 179.58.

Table 4. EDI calculations for conditions at Taman Beringin landfill site

Parameters	Unit	Concentration	Index (dp)	Weight (FW)	dp.FW	Exceeded Limits
BOD (w)	mg/L	84.6000	100.9109	3.2934	332.3399	Yes
COD (w)	mg/L	1,594.0000	118.2748	0.4117	48.6937	Yes
Chromium (w)	mg/L	0.0530	111.8088	0.6467	72.3068	Yes
Lead (w)	mg/L	100.4390	100.2381	0.6467	64.8240	Yes
Mercury (w)	mg/L	0.6700	100.7680	0.6467	65.1667	Yes
Manganese (w)	mg/L	2.8000	100.5676	0.6467	65.0371	Yes
Susp. Solids (w)	mg/L	413.0000	79.0482	0.5489	43.3896	Yes
Carbon Dioxide (g)	ppm	1.440E+02	0.0115	1.6467	0.0190	No
SO2 (g)	ppm	3.410E+01	0.0682	1.0978	0.0749	Yes
Hidrogen Sulphide (g)	ppm	1.888E+02	0.0378	0.8234	0.0311	Yes
Vinyl Chloride (g)	ppm	2.427E-03	0.0083	0.6587	0.0055	No
Styrene (g)	ppm	5.457E-02	0.1721	0.5489	0.0944	No
Benzene (g)	ppm	1.252E-05	0.0091	0.4705	0.0043	No
Ammonia (g)	ppm	2.004E-03	0.0027	0.3659	0.0010	No
CO (g)	ppm	0.000E+00	0.0000	0.3293	0.0000	No
Benzene (s)	mg/kg	0.0450	28.9053	3.2934	95.1967	No
Vinyl Chloride (s)	mg/kg	0.0430	22.9379	1.0978	25.1812	Yes
Ethylbenzene (s)	mg/kg	0.0500	12.5055	0.6587	8.2374	No
Lead (s)	mg/kg	95.3000	16.0866	1.0978	17.6599	Yes
Chromium (s)	mg/kg	77.1000	8.7046	0.6587	5.7337	No
Benzene (gw)	mg/L	0.0050	20.0000	3.2934	65.8680	Yes
Vinyl Chloride (gw)	mg/L	0.0040	15.5556	1.0978	17.0769	Yes
Ethylbenzene (gw)	mg/L	0.0070	20.8957	0.6587	13.7640	Yes
Arsenic (gw)	mg/L	0.0000	0.0000	1.6467	0.0000	No
Lead (gw)	mg/L	0.6160	42.9832	1.0978	47.1870	Yes
Chromium (gw)	mg/L	0.0740	31.2347	0.6587	20.5743	Yes
EDI						899.17

Table 5. EDI calculations at tolerable level (threshold limit values)

Parameters	Unit	Threshold Limits	Index (dp)	Weights (FW)	dp.FW
BOD (w)	mg/L	20.0000	23.8560	3.2934	78.5674
COD (w)	mg/L	50.0000	3.7100	0.4117	1.5274
Chromium (w)	mg/L	0.0500	105.4800	0.6467	68.2139
Lead (w)	mg/L	0.1000	0.0998	0.6467	0.0645
Mercury (w)	mg/L	0.0050	0.7520	0.6467	0.4863
Manganese (w)	mg/L	0.2000	7.1834	0.6467	4.6455
Suspended Solids (w)	mg/L	50.0000	9.5700	0.5489	5.2530
Carbon Dioxide (g)	ppm	5,000.0000	4.000E-01	1.6467	6.587E-01
Sulphur Dioxide (g)	ppm	2.0000	4.000E-03	1.0978	4.391E-03
Hidrogen Sulphide (g)	ppm	10.0000	2.000E-03	0.8234	1.647E-03
Vinyl Chloride (g)	ppm	5.0000	1.717E+01	0.6587	1.131E+01
Styrene (g)	ppm	50.0000	1.577E+02	0.5489	8.654E+01
Benzene (g)	ppm	10.0000	7.234E+03	0.4705	3.404E+03
Ammonia (g)	ppm	25.0000	3.312E+01	0.3659	1.212E+01
Carbon Monoxide (g)	ppm	25.0000	3.096E+01	0.3293	1.020E+01
Benzene (s)	mg/kg	0.0500	32.1170	3.2934	105.7741
Vinyl Chloride (s)	mg/kg	0.0010	0.5334	1.0978	0.5856
Ethylbenzene (s)	mg/kg	0.0500	12.5055	0.6587	8.2374
Lead (s)	mg/kg	85.0000	14.3480	1.0978	15.7512
Chromium (s)	mg/kg	100.0000	11.2900	0.6587	7.4367
Benzene (gw)	mg/L	0.0002	0.8000	3.2934	2.6347
Vinyl Chloride (gw)	mg/L	0.0000	0.0389	1.0978	0.0427
Ethylbenzene (gw)	mg/L	0.0002	0.5970	0.6587	0.3933
Arsenic (gw)	mg/L	0.0100	2.8944	1.6467	4.7662
Lead (gw)	mg/L	0.0150	1.0467	1.0978	1.1490
Chromium (gw)	mg/L	0.0010	0.4221	0.6587	0.2780

It is also important to emphasize here that the concentrations of the gas emission parameters used for calculation of LPI were simulated based on the Gaussion dispersion model, which predicts the concentrations of the emitted gases downwind from the boreholes where the gas emissions were measured. Atmospheric dispersion is only one of the environmental processes that require modelling in a comprehensive risk assessment (Griffiths 1991). The model was popularly used in describing the dispersion of the gases three-dimensionally after being released from a point source such as the boreholes (Zaini Ujang 1997). In this case, the concentrations of gases reach the target in certain distance from the boreholes such as the residents around the landfill areas could be estimated before it can then be compared with the threshold limit values.

Development of Landfill Pollution Index (LPI)

Based on the results of EDI_u (actual conditions) and EDI_i (Threshold limit values) calculations, the Landfill pollution Index (LPI) for the landfill sites were obtained, and summarised in Table 6.

Table 6. Landfill Pollution Index (LPI) for landfill sites

Landfill Sites	EDI_u	EDI_i	LPI ($EDI_u - EDI_i$)
Taman Beringin	899.17	179.58	719.58
Jinjang Utara	480.35	96.84	383.51
Paka 1	302.76	105.10	197.66
Brickfields	167.21	38.32	128.89
Paka 2	211.37	97.65	113.72
Sri Petaling	41.14	10.33	30.81
Sungei Besi	18.49	0.63	17.87

From the results of LPI calculations, it can be concluded that the pollution levels at Taman Beringin landfill site was the highest with the LPI of about 720. This shows that the levels of pollutants assessed at the landfill sites were very much exceeding the threshold limits. Other landfill sites that were found to have high LPI values were Jinjang Utara, Paka 1 and Brickfields landfill sites.

CONCLUSION

The development of a Landfill Pollution Index (LPI) to evaluate the pollution levels of landfill sites had been introduced, which has taken into considerations all the allowable threshold limit values and dose response relationships of selected parameters. Important parameters from different point of views in assessing the pollution levels of landfill sites have been identified and quantified by using the Delphi Method, which emphasises on the development of weightages or rankings for parameters.

The LPI is able to make the status of the existing landfill sites more accessible to the landfill operator, decision-makers as well as the general public in terms of the pollution levels. This can also be useful especially in providing important information to the landfill operators and decision-makers as database in the formulation and execution of a cost-effective and efficient remediation or reclamation plan on the landfill sites.

Generally, it can be concluded that the pollution levels of landfill sites in Kuala Lumpur area are site-specific and vary from one landfill site to another. Among the seven (7) landfill sites identified and studied in Kuala Lumpur, the active landfill site, i.e. Taman Beringin landfill site has been assessed as the most polluted site. However, the pollution levels at other landfill sites should not be taken lightly. All landfill sites in the study area were found to be facing certain levels of pollution. Special attentions should be given to those landfill sites with high level of Environmental Degradation Index (EDI) for particular components and also where certain parameters were assessed to exceed the allowable threshold limit values.

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